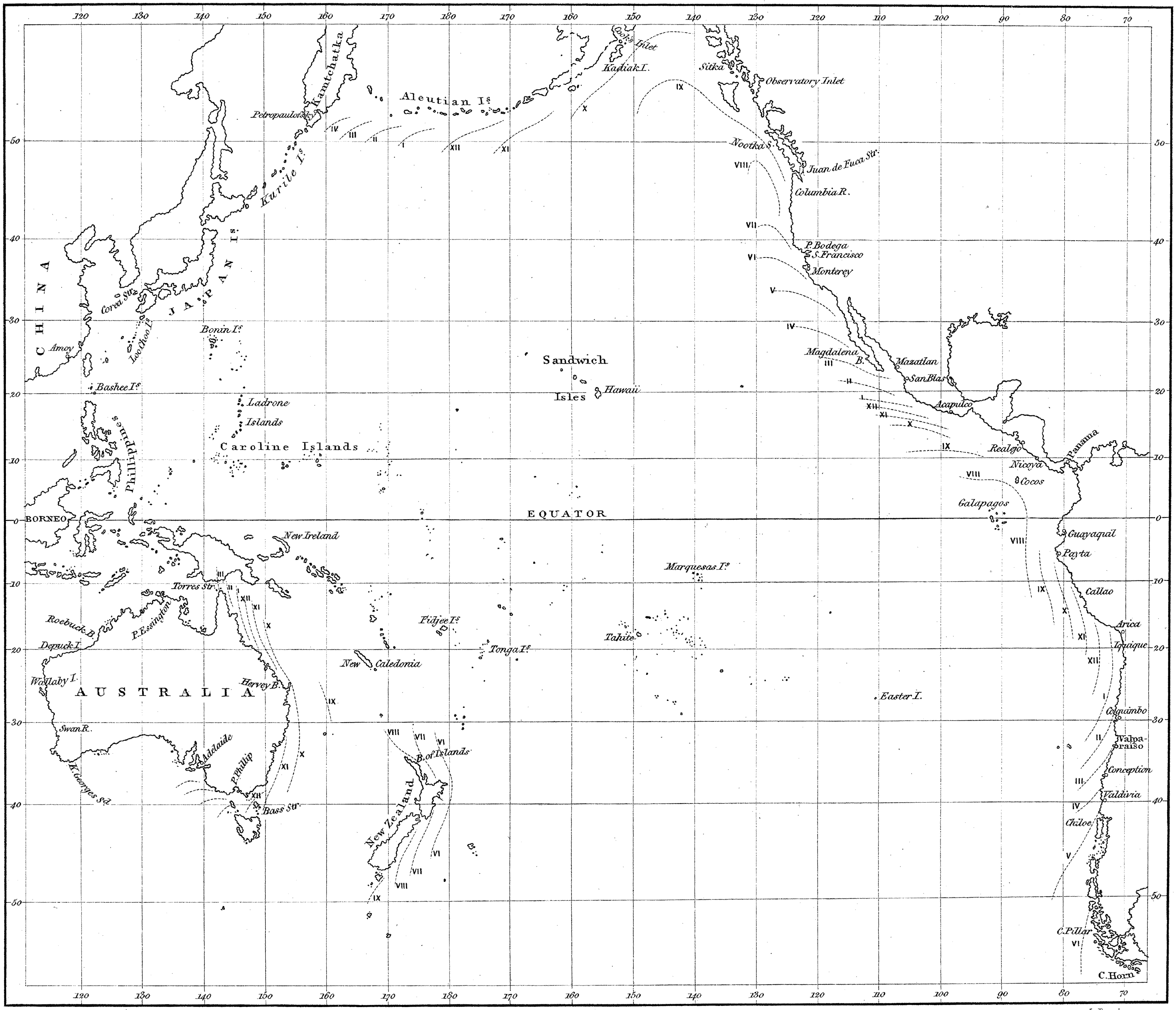


J. Basire, sc.

Chart to accompany Dr. Whewell's Memoir on the Tides of the Pacific 1848

PHILOSOPHICAL TRANSACTIONS.

I. The Bakerian Lecture.—*Researches on the Tides. Thirteenth Series. On the Tides of the Pacific, and on the Diurnal Inequality.*

By the Rev. W. Whewell, *D.D., F.R.S., &c.*

Received November 11,—Read December 16, 1847.

1. In 1833 the Royal Society did me the honour to publish, in its Transactions, a memoir of mine, entitled "Essay towards a First Approximation to a Map of Cotidal Lines;" and, in subsequent years, a number of further communications on the subject of our knowledge of the tides, as deduced from observations of those phenomena. These later "Researches" have modified my first views,—a result which I from the first contemplated as probable, as I intended to imply by entitling my memoir "An Essay towards a First Approximation," and as I expressed more fully in the memoir itself. I have also obtained from various persons, since my last communication to the Society, a considerable amount of recent tide observations, made in various quarters of the globe; and I am desirous of pointing out the general bearing of these additional materials of knowledge. I wish especially to bring under the consideration both of mathematicians and of navigators, the problem of the tides of the Pacific Ocean. When I wrote my first memoir on the subject, our knowledge of the tides of that ocean was so imperfect, that I did not even venture upon a first approximation to the cotidal lines. And I have since seen reason to believe that, not only for that ocean but for all large seas, the method of drawing cotidal lines which I formerly adopted, is very precarious.

2. There is another leading feature of the tides, which has been brought clearly into view in the course of these researches, which is of great interest and importance to the navigator, as well as to the mathematician, and of which I have assigned the laws in a general manner, and with an accuracy sufficient for most practical purposes; I mean the Diurnal Inequality which makes the common or semidiurnal tides differ alternately in excess and in defect. I have already examined various series of

tide observations in which this diurnal inequality prominently appears; but I have now the means of showing it to be much more extensively distributed and larger in amount than has been supposed.

These two points, the Cotidal Lines, and the Diurnal Inequality, will be the subject of the present memoir.

Of Cotidal Lines.

3. Great light was thrown upon the form of the cotidal lines by very extensive series of observations made for that purpose in June 1834 and June 1835, by the Preventive Service at all their stations on the coasts of England, Ireland and Scotland, and by naval officers at many points of North America, Spain, Portugal, France, Belgium, the Netherlands, Denmark and Norway. These observations, made at my suggestion, by the kindness of the authorities of that time, were so numerous and exact as to determine with considerable accuracy the form of the cotidal lines in the neighbourhood of the oceanic coast of Europe. One main feature, very prominent in all these lines, was that they meet the shore at a very acute angle, and follow its flexures at a little distance with an almost parallel course; and that consequently, the tide-wave which runs up a channel is, in the middle of the channel, very much in advance of its place at the sides of the channel*. This form of the cotidal lines is also easily shown to be in harmony with the laws of the motion of fluids†; and it cannot be doubted that those lines must affect such a form to a much greater extent than was assigned to them in my First Approximation.

This character of the cotidal lines must prevail to such an extent that I conceive all attempts to draw such lines *across* a wide ocean by means of observations on its shores, must be altogether worthless. This applies beyond doubt to the Pacific Ocean, and probably, taking other reasons into account, to the Atlantic also.

4. This conclusion is further confirmed by our finding that if we do draw "cotidal lines" across wide oceans, as for instance, the Atlantic, they do not agree with tides observed at islands in the mid-ocean, without ascribing to the lines such flexures as deprive them of all simplicity, and make them require further evidence.

5. Again, it is found that, for the most part, the tides in the mid-ocean isles are very small; and this circumstance again, makes the assumed oceanic continuity of cotidal lines very doubtful.

6. Further: if the tides in the Atlantic and Pacific be conceived to be brought by a progressive wave, which the scheme of cotidal lines assumes, they must be conceived to be brought from some part of the ocean where such a wave can travel round the globe of the earth so as to follow the moon, or at least, to be connected with such a part of the ocean: and such a supposition was accordingly involved in

* See the Charts of the British Isles and of the Coasts of Europe in the Sixth Series of Tide Researches, Philosophical Transactions, 1836, Part II.

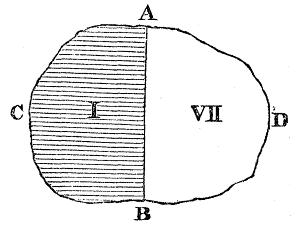
† See Mr. Airy on Tides and Waves, Art. 359, in the Encyclopædia Metropolitana.

the attempts to draw the cotidal lines of the Atlantic and Pacific. But it appears unlikely that this supposition rightly represents the mode in which the waters of the Atlantic and Pacific obey the action of the sun and moon.

7. If it be asked what other mode of operation of the lunar and solar forces upon the ocean can be conceived, different from this progressive wave which is expressed by means of cotidal lines; an answer immediately suggests itself, that a *stationary undulation,* corresponding in its period with the period of the moon's apparent revolution, from meridian to meridian (that is, a lunar half-day), is a possible mode of motion for a fluid under such circumstances. By a "stationary undulation," I mean a motion such as that which takes place in a vessel of water, when one side is suddenly lifted from rest, and then set down again. When this is done, the water oscillates, the surface rising alternately on the raised side and on the other, and the middle line of the surface neither rises nor falls. In this case the oscillation is *free,* depending on the dimensions of the fluid only: but if the fluid were subject to periodical forces, such as an attracting body passing over it at equal intervals of time, it might perform *forced* oscillations of the same kind; and in this case, the period of the oscillation would necessarily, in the ultimate condition of the fluid, be the same as the period of the forces.

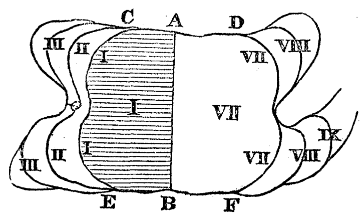
8. The lunar attraction passes over every wide ocean once in every lunar half-day; and it is conceivable that such an ocean, under the influence of the lunar forces, should perform, every lunar half-day, such a stationary oscillation as has been described. On this supposition, we should have a regular tide at its eastern and western shore, but no tide in the middle part; and in such a case there would be no cotidal lines. The ocean would be divided into two portions or areas by a *line of no tide* (AB); and these two areas would each have the tide over the whole area at the same time, the two times differing by six lunar hours. For instance, if the time of high water on the eastern shore, ACB, were one o'clock, the time of high water on the western shore, ADB, would be seven o'clock. This might be expressed by distinguishing the two spaces by shading, and marking them I. and VII. respectively. (See fig. 1.)

Fig. 1.



9. But this cannot be a representation of the state of the tides of oceans generally, at least as to their *littoral* spaces. For we know by observation that, along large tracts of the shores of all seas, the tide does travel progressively, in such a manner that its course in those parts may be represented by a series of cotidal lines. And if the shore be broken by shallow inlets and bays, the tide must, by the laws of fluids, travel progressively up these recesses. In such cases, we may properly represent the state of the tides by such a diagram as before, bordered with a series of cotidal lines representing the course of the tide into the

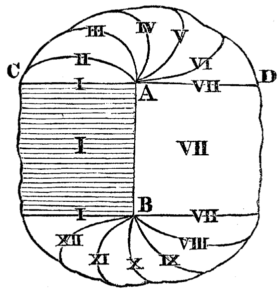
Fig. 2.



recesses of the coast; which will be expressed by drawing the cotidal lines of two hours, three hours, &c. (II. III., &c.) belonging to the tides derived from the oceanic tide I.; and by drawing the cotidal lines of VIII. IX., &c., derived in like manner from the oceanic tide VII. (See fig. 2.)

10. But, moreover, if CD be the shore transverse to the line of no tide AB, it is very possible that the tide may not be absolutely simultaneous from C to D, but may vary continuously along this shore, although the tide in the central oceanic parts be of the nature of a stationary undulation, as already supposed. In this case, the state of the tides will require that, in a map, we should place the extremity A of the line of no tide at some distance from the shore, and there will be a series of cotidal lines I. II. III. IV. V. VI. VII., which will revolve about the point A, and will carry the tide in succession to all the points of the coast CD. These lines will have the general form of cotidal lines which we have described; and will be determined in their details by the shore along which the progressive tide-wave travels. (See fig. 3.)

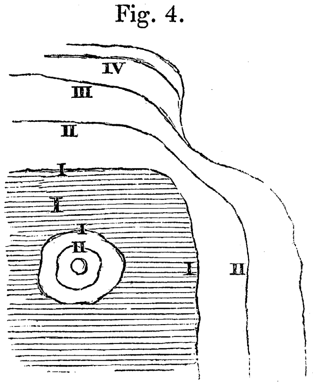
Fig. 3.



11. But there is yet another modification which the cotidal spaces of the oceanic tides undergo, in passing into the cotidal lines of littoral tides. The oceanic tides produced by a stationary undulation, with its midline of no tide, give tides necessarily differing *six* lunar *hours* from each other on the opposite sides of the ocean. It is high water on one side when it is low water on the other. Now this cannot be the case all over an ocean which is of different breadths in different parts; nor, in fact, can it be the case in any part of it. For that motion of the parts of the fluid which a stationary undulation requires, cannot take place on a shore shallow in proportion to the depth of the oceanic spaces. Near the shore, we shall have a tide which is progressive from the oceanic space towards the land. Hence, even when the tide occurs at the same time along a great extent of shore on one side of an ocean, we cannot assume that it is directly produced by the oceanic tide. It may be a tide which is later than the oceanic tide, and which may be represented by a cotidal line bordering the space which the oceanic tide occupies. (See fig. 4.)

12. And this may be the case with regard to a detached island, as well as to an extensive coast; especially if the island be the summit of an extensive part where the ocean grows shallower. In such a case the island may have about it cotidal lines in the form of rings. (See fig. 4.)

Fig. 4.



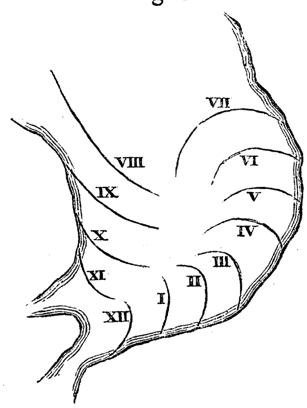
13. From these considerations, it appears that it must be very difficult to determine the time of high water in the oceanic spaces. All that can be certainly known is, that the time must be earlier than the earliest neighbouring littoral tides. And such an oceanic tide being assumed, the

sequence of the tide-hours along the shore may be rightly represented by cotidal lines drawn nearly parallel to the shore, according to the data which observation supplies.

14. It is to be observed, however, that the oceanic tide necessarily includes two different areas, in which the times of high water differ by six lunar hours; and therefore that which is assumed as the oceanic space, must be so situated that the tides on its opposite sides differ by about six lunar hours. The oceanic space thus occupied by the stationary undulation must, further, be so situated that the tides in its middle parts are small or disappear.

15. But a stationary undulation, such as has been supposed to occupy the oceanic space, is not the only mode in which we may conceive large littoral tides combined with small central tides. Such a combination may be produced by cotidal lines revolving round a fixed centre, as in the upper part of figure 3. Nor is such a state of things imaginary only. The course of the tides on the opposite coasts of England and the Netherlands is such as not to be intelligible in any other manner than by supposing such a rotation of the tide-wave, as may be seen in my Sixth Series of Tide Researches. And the smallness of the tide in the central parts, which this view of the subject implies, has been verified by the observations of Captain HEWETT and others. A case somewhat of the same kind occurs on the coast of Ireland. At Courtown on the east coast, there is no lunar tide*, though there is a progressive tide-wave on the opposite coast of Wales.

Fig. 5.



16. It may be thought, therefore, that we shall find it impossible to decide whether the tides of an ocean in which the central tides are small and the littoral tides progressive, are to be represented by a revolving wave or by a stationary oceanic undulation with bordering cotidal lines. But this difficulty is not of much real consequence; for one of these hypotheses passes gradually into the other, as may be seen in fig. 3. And the result of both the one and the other is, that we cannot pronounce anything certain about the time of high water in the oceanic space, till we have been enabled, by numerous observations, to draw the littoral cotidal lines with considerable accuracy; and when this is done, the nature of the oceanic movement will probably show itself upon the face of our chart.

17. On these grounds, I am now disposed to retract parts of what I have said with regard to the form of the cotidal lines of the Atlantic in my "Essay." I do not think it likely that the course of the tide can be rightly represented as a wave travelling from south to north between Africa and America. We may much better conceive the state of things by means of a stationary undulation, of which the middle space is between Brazil and Guinea, in which region the tides are very small, as at St. Helena

* See Mr. AIRY in the Philosophical Transactions, 1845, Part I.

and Ascension; while at Tristan d'Acunha, a detached island like the others, but removed out of this medial space, the rise is eight or nine feet. This would explain also many of the circumstances which made it so difficult to give any possible form to the cotidal lines in the Atlantic; for instance, the tide occurring nearly at the same time all the way from the Cape of Good Hope to the Congo. This is accounted for if we suppose that the South Atlantic is mainly occupied by the oceanic tide, and that this area is bordered by cotidal lines nearly parallel to the shore. I must confess, however, that at present I am unable to carry this hypothesis into comparison with the general body of the facts. Such a comparison would require observations much more numerous than we as yet possess; and, as I have already said, even with numerous observations, we can only hope to draw the cotidal lines in the neighbourhood of the shores.

18. For the same reason I shall not attempt to determine the general course of the tides in the Pacific; but I will remark that the view now given of the distribution of the tides in an ocean explains several of the features of the Pacific tides which were before very perplexing. If we suppose an ocean tide from the borders of which proceed tides having their progress marked by cotidal lines, we can easily draw the lines so as to include the following facts of observation:—

(1.) The *easterly* motion of the tide-wave round Cape Horn, which is established by Capt. KING's observations*, and which, as I formerly observed†, is difficult to reconcile with the supposition of a tide revolving from west to east round the south pole. This is explained by its being a tide proceeding from the oceanic tide.

(2.) The tide being at nearly the same hour along a large portion of the coast of South America, namely, from the western extremity of the Straits of Magellan for twenty or thirty degrees northward. This shows that the cotidal line is nearly parallel to the shore.

(3.) The very small tides or no tides at the islands in the centre of the Pacific, Tahiti, and the Sandwich Islands. These belong to a central portion of the ocean, where the rise and fall of the surfaces nearly vanishes.

19. I shall now proceed to give such materials for a knowledge of the tides of the Pacific as I have been able to collect, in addition to those which I had under my notice in my former Essay. They are for the most part derived from tide observations made under the direction of naval officers employed on expeditions of survey and discovery. The series of observations at each place was often necessarily brief and inexact; and therefore it is no reflection upon the skill and care of the officers and men to whom we owe them, to say that they are often wanting in correctness.

20. There are, moreover, two other sources of inaccuracy in tide observations; namely, the want of a clear understanding as to the thing to be observed, and the irregularity or complexity of the facts themselves. With regard to the former point, I hope that several misapprehensions formerly prevalent among navigators are now

* Sailing Directions.

† Philosophical Transactions, 1833, p. 192.

no longer common, such as confounding the time of high water with the time of turn of the tide-stream. But there is probably still some unnecessary difficulty produced by regarding, as a cardinal point in the observation, the "establishment," as vulgarly understood, namely the hour of high water *on the day of new or full moon*; for, in fact, the hour of high water on this day is of no more importance than the hour of high water on any other day, except in so far as it gives the means of knowing the hour on other days. And it does not afford the means of doing this, any more than the hour of high-water for any other given age of the moon does. For just as much inaccuracy as, from whatever cause, there is, in deducing the time of high water at all ages of the moon from the time at a given age, just so much inaccuracy is there, from the same causes, in deducing the time of high water for all ages of the moon, from the time for full or new moon. And if the time at which the tide follows the moon on two or three successive occasions, be greatly and irregularly different, the observations are equally of little value, (either for drawing cotidal lines, or for predicting tides, or for any other purpose,) whether any of the observed tides fall on the day of new or full moon, or do not. If the tides are regular and the observations good, the common "establishment" may be obtained from the observations of any one day; although to give much value to this deduction, the tides should be observed for a fortnight. And if such observations be made for a number of very distant places, the common "establishment" does not represent a corresponding fact at different places. In some places it means the time of high water one day after the highest tide; in some, the time two days after the highest tide; in some, three days; for the "age of the tide" is different at different places, and the tide which corresponds to the new or full moon comes after the new or full moon by one, two, or three days. Hence, in order that we might compare the tides of distant places by means of a fact which had the same meaning in all of them, I proposed, in my former Essay, instead of taking this common Establishment, to take what I then called *the corrected Establishment*, namely the *mean* of all the lunitidal intervals, that is, of the intervals by which the tide follows the moon's transit. And this corrected establishment I used in the discussion of the extensive series of observations made in 1836. In general, the corrected establishment is about thirty minutes less than the common establishment. It has been used by Admiral Lütke in his discussion of the tides of the Pacific. As however the common establishment is still the one familiar to navigators, and as no material error will result from the use of it, I shall make it the basis of my remarks on the tides of the Pacific. But it may be useful to bear in mind what I have said, that this "establishment" may be deduced from observations not made at the new or full moon*.

A very simple and convenient way of recording the result of a tide observation on any day, would be to state the *time of moon's transit* (which is given by the tables

* I have here said that in cases where the tides follow the common laws, we may deduce the time of high water on one day from the time on another: I might have said the same thing of the heights.

without observation) and the time at which the high water follows the moon's transit (*the lunitidal interval*); for the comparison of such intervals in successive half-days would immediately show whether the observations give any consistent result: and if they do not, they must be of little value. This test I have accordingly applied to the observations hereafter quoted. Where the lunitidal intervals on successive half-days differ very much (by two or three hours, for instance), or follow some progression inconsistent with the usual laws of the tides, the results of those observations can be of no immediate value, either for drawing cotidal lines, or for any other purpose.

21. But besides the irregularities in the observed tides arising from inaccurate or confused processes, there are others arising from the phenomena themselves. For instance, there are some places where the tides are regulated by the sun as much as they are by the moon, or even more. At these places we should obtain no intelligible result by referring them to the moon alone. Again, in other places the lunitidal interval is affected by a large inequality which makes it alternately greater and less: for instance, in successive tides it is, (in minutes,)

30, 150, 60, 180, 30, 210,

and so on. Now what shall we say is the "establishment" in such a case? If we take the "corrected establishment," as I have defined it (the mean interval), it is 110^m; but this is not an approximate value for any single tide. If we take the three smaller intervals, which may happen to be the day tides, we have, for the mean, 40^m; if we take the three others, we have 180^m, or three hours. And if we use the common "establishment," the confusion is still greater. The fact is, that in such cases the term "establishment" loses all definite meaning, as I have already observed*. It cannot be of use, either in expressing the laws of the tides at any one place, or the mode of transmission of the tide from one place to another. The former subject, the law of the diurnal inequality of the tides at a particular place, I have been able to assign for several places, and in some degree, in general. The latter, the mode in which the diurnal and the semidiurnal wave are transmitted and continued, is a more difficult question. I shall however add a few words on each of these points.

22. Before I quit the subject of cotidal lines, I may remark, that Capt. FITZROY has pointed out the difficulties which attend the representation of the tides of the Atlantic and Pacific by means of cotidal lines, and has suggested a "libration or oscillation" of the ocean as better explaining the phenomena†. I had already, in 1836‡, pointed out other difficulties which belong to the case of the Atlantic, according to the series of observations then made.

We must recollect, however, that there are other ways besides the two which I have noticed (a stationary undulation and a revolving tide-wave) which will give us

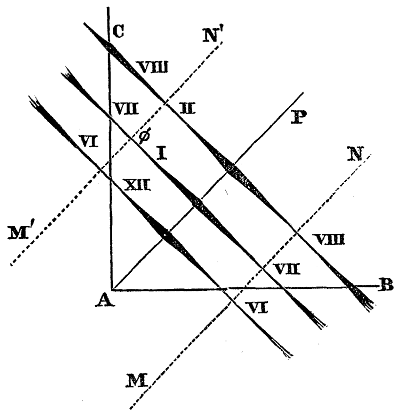
* Philosophical Transactions, 1840, Part I., p. 164.

† Voyages of the Adventure and Beagle. Appendix, p. 277.

‡ Philosophical Transactions, 1836, Part II., p. 304.

the result of a sea with considerable tides in some parts, and with spaces of no-tide. This may happen by the interference of two different tides; for instance, if two tide-waves differing six hours in the hour of high water arrive at any place, the two tides will destroy each other, and there will be no tide. And this may occur in a more complex manner. Thus, as Mr. AIRY has remarked*, if two equal rectilinear waves, transverse to each other, travel across the same ocean, in directions AB and AC, the result will be that compound waves will travel in the direction AP which makes equal angles with the two directions AB and AC. But in this case there will be certain lines MN, M′N′, parallel to AP, along which there will be no tide. And though the lines which mark the compound waves may be considered as the cotidal lines, these lines will be discontinuous, and the parts outside of the space MN, M′N′ will be separated by six hours from the parts within that space. This example shows also how partial and limited cotidal lines may be, and how precarious must be all inferences on that subject from a few points to wide oceans.

Fig. 6.



23. The complex cases of tides appear at first sight to be interpreted in a different manner when we draw complex cotidal lines, as in Article 15, and when we suppose a combination of simple undulations, as in the last Article. But this difference of interpretation does not necessarily exist, if we conceive the cotidal lines to be mere *geometrical diagrams*, not lines marking the progress of a wave by motions of the particles perpendicular to the line of the wave. With this extension of the notion of a cotidal line, such lines may still be used to represent, in the first instance, the results of tide observations made at a series of places in the same seas; nor does it appear that there can be at present devised any better method of bringing tide observations into geographical combination, than this method of drawing cotidal lines. The case of the tides of the German ocean, for instance, where the order of the tide-hours had led me to draw the cotidal lines as converging to a centre of *no-tide* (as in Article 15), has been differently explained by Mr. AIRY†. He conceives that these tides arise from the combination of a tide running along the eastern coast of England to the south, with a tide coming through the Straits of Dover to the east. But the combination of these two tides would, in fact, produce such cotidal lines as I have drawn, with a point of no-tide where I had predicted it, and where it was found by Capt. HEWETT. It is true, that on this supposition the point of *no-tide* would not be a point of rest of the ocean; nor did I ever suppose that it would be so. There is, at the point of no-rise-and-fall of the surface, a considerable stream of tide alternately north-east and south-west, as Capt. HEWETT found. And the same will

* Tides and Waves, Art. 367.

† Ibid. 526.

probably be the case in other instances where the cotidal lines affect the same converging form, and where the tide in the central part of the sea vanishes.

Materials for a Tide Map of the Pacific.

24. The materials which I formerly employed in my "Essay towards a First Approximation to a Map of Cotidal Lines," were principally the following:—the collection of the facts then known, given in the fourth volume of LALANDE's Astronomy; Books of Astronomy and Navigation, and Sailing Directions, as NORIE's Epitome of Navigation, PURDY's Memoir on the Atlantic Ocean, his Memoir on the Ethiopic or South Atlantic, and his Columbian Navigator: Nautical Surveys, as the Surveys of the Australian coasts by Captains FLINDERS and KING, and of Patagonia by the latter officer; and the Survey of the Pacific by Captain BEECHEY; also foreign materials of the same kind, as MALASPINA's Voyage, and ROUSSIN's Survey of Brazil: to which may be added the "Remark Books" of various ships, which I was allowed to consult at the Admiralty, Memoirs relative to particular places, and other miscellaneous sources of information.

25. I have more recently collected other materials of the same kind, which I will briefly describe. They are partly gathered from books: for instance,—

Voyage autour du Monde sur l'Uranie et la Physicienne, pendant les années 1817, 1818, 1819, 1820, par M. L. DE FREYCINET. Paris, 1826.

One volume of this work, consisting of 356 pages, is entirely filled with tide discussions; and it is mortifying to see so much zeal and mathematics thrown away from the want, so general even yet, of a knowledge of the best modes of dealing with tide observations. The observations were only made at four places: at Rio Janeiro, sixteen days; at the Isle de France, twenty-seven days; at Rawak, fifteen days; at Guam, nine days. With the whole of the discussion employed, little or nothing of value is obtained; for even the resulting "establishments" are too vague to be depended on.

In the Voyage of the Astrolabe under the command of M. J. D. D'URVILLE, 1826 to 1829, I do not find any tide observations recorded.

26. Voyage autour du Monde sur la Fregate la Venus, 1836 à 1839, par ABEL DU PETIT-THOUARS.

This navigator gives the "establishment" and rise of tide at fifteen places, principally on the western coast of America and in other parts of the Pacific. These results will be used in the present memoir, along with others; but I will insert here the general remarks which M. DU PETIT-THOUARS makes upon the subject, after giving his results.

"When we see from this table that the tide rises only one-fourth as high at Acapulco as at la Magdalena; when we remark differences of two hours and a quarter, and of four hours and a half between the tide-hours of ports at small distances from each other, and situate on a coast on which the ocean has free range; when

we note that the interval of three hours intervenes between high water at Payta and at Callao; no one can maintain that the question of the tides is exhausted, or even that there is not a great deal to be done, in order to decide in what manner invisible obstacles, as the inequalities of the bottom of the sea, act upon the velocity of propagation of the tide-wave and upon its height. In the age in which we live, to propose a scientific question in a distinct form is half its solution."

I may remark that the object of the present memoir is mainly to give additional distinctness to the problem thus proposed, in order that further observations and calculations may help us on to the solution.

27. In Captain FitzRoy's "Narrative of the Surveying Voyages of H.M.S. Adventure and Beagle, between 1826 and 1836," there are in the Appendix, two articles on the tides; one, containing the time and rise of the tide at a great number of places, the other containing some general remarks, to which I have already referred. Captain FitzRoy notices the features in the tides of the Pacific partly as Admiral Du Petit-Thouars does. Thus he says (p. 281),—

"It is high water at Cape Pillar and at Chiloe, including the intermediate coast, almost at one time: from Valdivia to the Bay of Mexillones (differing eighteen degrees in latitude) there is not an hour's difference in the time of high water: from Arica to Payta the times vary gradually as the coast trends westward: from Panama to California, the times also change gradually as the coast trends westward: and from forty to sixty north, high water takes place at one time."

Captain FitzRoy combines these and many other facts respecting the tides into a hypothetical general view of the movement of the ocean, which may be of service in provoking further inquiry, though it can hardly be considered tenable in detail, as perhaps the present memoir may serve to show.

28. In the Philosophical Transactions for 1840*, I mentioned and discussed certain remarkable tide observations made at Petropaulofsk in Kamtschatka, which I had received from Admiral Lütke. That officer has since combined several tide observations of his own and others, in a "Notice sur les Marées Périodiques dans le Grand Ocean Boreal et dans la Mer Glaciale," and has, in a chart of the North Pacific attached to this notice, drawn the cotidal lines belonging to that ocean. I will place here an extract from this Notice, pointing out the grounds on which he proceeds, and the difficulty in which he finds himself involved.

"In examining the order of sequence of the tide-hours on the west coast of America and in the Aleutian Isles, we see clearly that the tide coming from the south runs along this shore to the north-west; and then to the west along the chain of the Aleutians to the coast of Kamtschatka, employing twelve hours in passing from San Blas to Petropaulofsk. Proceeding from this point, we can no longer follow it with the same certainty, having no data for the tides at the Kurile Isles and on the eastern coast of Japan. Further to the south we again have some obser-

* Part I., p. 161.

vations (Loo Choo, Bonine, Rawak, Guahan) which show well enough the position of the cotidal lines of IX^h., X^h. and XI^h. And continuing these lines with those more to the north, we recognise here, with sufficient probability, the same undulation which, stopped by the coast of Kamtschatka, takes a southerly direction and reaches those shores. The difference noticed above between *the age of the tide* at Rawak and at the stations more to the north, agrees very well with this supposition, according to which the tide would make three-fourths of the circuit of this sea in eighteen hours.

"But here we are stopped by a dilemma very difficult to resolve, at least without the help of new observations. About 200 leagues to the south-east of the line of XI^h., we should, according to what we have hitherto seen, expect to find the line of XII^h., or thereabouts. But we find here at two or three places (Ualan, Radak, &c.), the tide-hour four hours or five hours, and we ask ourselves what can it be which retards the propagation of the tide-wave, so as to make it employ six hours in traversing a space which under ordinary circumstances it would pass over in one hour."

It will appear, I think, from the whole of what has preceded, that this difficulty is one which occurs in every part of the ocean, and can only be explained, or indeed its nature ascertained, by drawing the cotidal lines on a larger mass of observations.

29. Capt. Sir E. BELCHER's voyage has also supplied numerous observations of the tides in various parts of the Pacific, which he has kindly placed at my disposal, and which have been discussed by Mr. D. Ross of the Admiralty. In like manner Mr. Ross has discussed tide observations supplied to me by Capt. Sir JAMES CLARKE ROSS during his last voyage; also some tide observations by Capt. STOKES, Capt. KELLET, and some others which may be noticed hereafter.

30. I may take the liberty of remarking that many of these observations, being given as they were originally recorded, show how very imperfect is the accuracy which can be obtained on such occasions, when the series of observations is short and the apparatus necessarily rude. They thus show that the "establishment" deduced from such observations cannot be considered as entitled to much confidence. I will, for the sake of example, explain further what I mean. The "establishment" is the interval of time by which the tide follows the moon, either at new and full moon, which is the *vulgar establishment*, or its mean value, which is my *corrected establishment*; and whichever be taken, the term has no meaning, and observations made to determine the establishment have no value, except so far as this interval is definite in itself, and is determined by the observations. If the tides be regular and the observations good, this interval differs from day to day, sometimes as much as ten or twelve minutes on successive days, (in virtue of the *semimensual inequality*,) but on the whole fortnight, little more than an hour (its most usual value is 1^h 20^m). If therefore this interval, as observed in successive tides, differ by two or three hours, there must be some cause of irregularity either in the tides or in the mode of obser-

vation, which deprives the results of their value. We should not be justified in disturbing any previous determinations of the "establishment," on the ground of new observations of this kind; although it is true, that for aught we know, the previous determinations may rest on no better data. To show the extent to which this may go, I will give the values of the lunitidal intervals as they result from some recent observations on the west coast of America.

Lunitidal intervals observed.

Place.	Lat. S.	Long.	Interval.		Range.		Observed.
			Greatest.	Least.	Greatest.	Least.	
	° ′		h m	h m	ft.	ft.	
Callao	12 3	......	7 25	3 0	2	½	12 tides.
Puna Island	3 37	......	6 16	3 24	13	11	15 tides.
	North.						
Panama	8 57	......	4 0	1 48	15	9	17 tides.
Nicoya	9 56	......	3 50	1 24	10	6	40 tides.
Reafejo	12 28	......	3 20	1 10	13	1	31 tides.
Acapulco	16 50	......	3 0	1 12	1½	½	10 tides.
Magdalena Bay	24 38	......	9 30	5 24	6	3	13 tides.

I have added the range of the tide, that it may be seen whether the case was one in which much accuracy was to be expected. It is evident that at such places as Callao, where the tide ranges only from half a foot to a foot and a half, or two feet, it must be very difficult, especially by any rude apparatus, to determine with any accuracy the time of high water; accordingly we see that the interval, as observed, varies nearly four hours and a half. But at a place where, as at Panama, the tide ranges from nine to fifteen feet, it is more surprising to find the lunitidal interval varying as much as $2^h\ 12^m$. I am not however disposed to question the correctness of these observations; for the *diurnal inequality*, added to the semimensual inequality, may make the difference as great as this: and it will be observed that the mean result, $2^h\ 54^m$, would give an "establishment" about $3^h\ 24^m$; not differing much from the establishment given by Mr. LLOYD*, namely $3^h\ 20^m$.

31. I shall now proceed to give the tide-hours for the coasts of the Pacific, according to the best accounts which I find, judging them in the manner I have described. After noticing the course of the tide near Cape Horn, I shall follow it along the whole western coast of America, till, in the north, we reach the Aleutian Isles; and then, following this chain of islands, to the shores of Kamtschatka. I shall then consider the islands in the central parts of the Pacific, and proceed from them westward, according to my materials.

I have already, in my first Essay, shown that round Cape Horn, the tide-wave has an *easterly* motion. Thus, as I have there said, according to Captain KING†, at Cape Pillar it is high water at 1^h on the day of full and change; at York Minster, 5° of longitude to the east, it is at 3^h; at Cape Horn, 3° further east, it is at $3\frac{1}{2}^h$; in Good

* Philosophical Transactions, 1830.

† Sailing Directions, p. 96, and Table, pp. 13, 14.

Success Bay, in Strait le Maire, the hour is 4; on the east side of Strait le Maire it is 5^h. It appears also from Captain KING's observations*, that the tide travels in the same direction along the coast, that is, to the northward, on the eastern shore of Patagonia. This direction appears by Capt. FITZROY's Tables† to continue as far northward as latitude 40°, the wave employing about twelve hours in travelling from latitude 50° to 40° south. Along this coast the tides are very large; at Gallegos River, in latitude 52°, they rise forty-six feet. This circumstance might lead us to imagine that they are the result of accumulated waves converging from the north as well as the south; and this is probably the case. Yet it is remarkable, especially when considered in connection with this view, that in the great estuary of the Plata there is no perceptible tide‡.

I shall not, however, dwell at present upon the tides of the Atlantic, and shall proceed to those of the western coast of America.

Those observations which I now take account of for the first time are marked with an asterisk (*).

West Coast of America (South).

	Lat. S.	Long. W.	Tide-hour.	Greenwich time.		
	° ′	h m	h m	h m	ft.	
Cape Pillar	52 46	5 0	1 0	6 0		
Chiloe	41 52	4 57	11 30	5 0	6	King's Table, p. 15.
———	......	......	12 30	......	12	Heron, R. B.
Valdivia	39 50	4 56	11 30	3 26	...	Norie—Purdy.
———	......	......	......	3 30	...	*FitzRoy, p. 284.
Conception	36 49	4 53	10 0	2 53	...	Malaspina.
Valparaiso	33 2	4 45	9 25	2 10	...	Malaspina.
———	......	......	9 40	......	4	*Du Petit-Thouars.
Coquimbo	29 54	4 45	9 20	2 5	...	Remark Books.
———	......	......	......	2 0	...	*FitzRoy, p. 285.
Iquique	20 0	......	......	1 30	...	*FitzRoy, p. 285.
Arica	18 28	4 40	......	......	...	*FitzRoy, p. 285.
Callao	12 4	5 7	6 15	......	...	Malaspina.
———	......	......	6 0	11 7	$2\frac{1}{2}$	*Du Petit-Thouars.
Payta	5 3	5 24	3 18	......	6	*Du Petit-Thouars.
Guayaquil.						
Puna Island	3 27	5 19	5 0	......	12	*Capt. Sir E. Belcher.
Punta Piedra	3 30	5 19	6 10	......	10	*Capt. Kellet.
Galapagos.						
Charles Island	1 15	6 2	2 10	8 12	...	*FitzRoy, p. 84.
Chatham Island	1 0	5 54	3 30	......	...	Purdy, E. M.
Ile Charles	......	......	3 19	......	6	*Du Petit-Thouars.
	North.					
Cocos	5 34	5 15	2 10	7 35	...	Purdy, E. M., p. 50. Vancouver.
———	......	......	4 0	......	...	Purdy, E. M., p. 47. Colnett.
———	......	......	......	8 0	...	*FitzRoy, p. 285.
Panama	8 57	......	3 20	......	...	Lloyd, Phil. Trans., 1830.
Panama Bay	......	5 18	4 0	......	13	*Capt. Kellet.
———	......	......	3 36	8 54	15	*Sir E. Belcher.

* Sailing Directions, p. 17.

† App. p. 66.

‡ FITZROY, App. p. 280.

West coast of America (North).

	Lat. N.	Long. W.	Time, high water.	Greenwich time.	Rise.	
	° ′	h m	h m	h m	feet.	
Nicoya	....	....	....	8 0	....	*FitzRoy.
Island S. Lucas	9 56	5 42	3 0	8 42	6	*Sir E. Belcher.
Realejo	12 28	5 48	3 0	8 48	6	*Sir E. Belcher. Great irregularities.
Acapulco	16 50	6 39	2 41	9 20	1	*Sir E. Belcher.
———	....	....	3 5	9 44	2	*Du Petit-Thouars.
Magdalena Bay	24 38	7 28	8 30?	....	6	*Sir E. Belcher. Very anomalous.
———	....	....	7 37	3 5	10	*Du Petit-Thouars.
San Blas	21 32	7 1	8 5	3 6	....	Mem. on South America.
———	....	....	....	3 0	....	*FitzRoy.
———	....	....	9 41	4 42	....	*Beechey.
Mazatlan	23 0	7 10	9 50	5 0	....	Beechey.
King George's Sound	35 2	7 52	11 30?	....	3	*Sir E. Belcher. Very anomalous.
Monterey	36 36	8 6	9 42	5 48	....	Beechey.
———	....	....	9 52	....	7	*Du Petit-Thouars.
San Francisco	37 48	8 9	12 30?	....	6	*Sir E. Belcher. Very anomalous. Diurnal inequalities, high water and low water, large in height and times.
———	....	....	10 52	....	....	Beechey and Malaspina.
———	....	....	10 33	6 42	6	*Russian navigators (Lütke's notice).
Port Bodega	38 19	8 11	11 41	7 52	....	*Russian navigators.
Columbia River	46 16	8 16	1 0	9 16	8	*Sir E. Belcher.
———	....	....	1 30	....	....	Vancouver.
Straits of Juan de Fuca	48 0	....	12 30	....	8	*Capt. Kellet.
Nootka Sound	49 36	8 25	12 30	8 55	....	*Cook.
Sitka	57 2	9 2	10 40	....	12	*Sir E. Belcher. Great diurnal inequality.
———	....	....	12 33	9 35	12	*Lütke.
F. Nicolaefsky (Cook's River)	60 15	10 6	3 49	1 55	28	*Wrangell.

From this point the coast turns westward, and the stations are arranged according to longitude without regard to their latitude.

	Lat. N.	Long. W.	Time, high water.	Greenwich time.	Rise.	
	° ′	h m	h m	h m	feet.	
American Coast.						
*F. Nicolaëfsky (Cook's River)	60 15	10 6	3 49	1 55	28	*Wrangell.
Harbour of St. Paul (Kadiak Island)	57 46	10 8	0 30	10 38	10	*Russian navigators.
Harbour 3 hiérarq	57 8	10 12	0 19	10 31	10	*Russian navigators.
Nouchagak Bay	58 31	10 34	2 14	0 48	12	*Wrangell.
Aleutian Isles						
*St. Paul Island	57 10	11 20	3 47	3 7	4	*Russian navigators.
Atkha Island	52 25	11 36	0 20	11 56	5	*Russ. navigators: doubtful.
Attou Island	52 57	12 28	0 48	1 16	22	*Russ. navigators: doubtful.
Kamtschatka.						
Petropaulofsk	53 1	13 26	3 38	5 4	4	*Lütke in 1827.
———	....	....	3 43	5 9	....	*Lütke in 1828, diurn. ineq.
———	....	....	3 54	....	3	*Du Petit-Thouars.

32. Looking at the general assemblage of the numbers which occur in the column marked "Greenwich time," it is evident that the tide-wave of the hour VIII. which

is at Cocos Island and at the Galapagos about eight o'clock, comes to the continent at Nicoya and Realejo about 10° and 12° north latitude at about three quarters of an hour later; while the tide is at hours later than this, both to the northward and to the southward. Proceeding first southward, we find the line of XI. not far from Callao, that of II. near Coquimbo, or Valparaiso, and that of III. and a half, near Valdivia: and further south, we have the line of V. at Chiloe, and of VI. at Cape Pillar, whence the wave moves to the eastward round Cape Horn, as already stated. Considering these points as fixed, it is easy to interpolate the other cotidal lines along this coast. The observed hour at Guayaquil is later than its position would give, a result which we should expect, since the tide will occupy some time in travelling up the gulf in which Guayaquil is situated.

Again, proceeding from Nicoya and Realejo to the northward, we find a like progression of tide-hours. The line of X. is not far from Acapulco, according to the data here collected. But the tide at Acapulco is small, and hence the accuracy of the result is doubtful. Perhaps the smallness of the tide is an indication that the point of divergence of the tide-wave, which occurs on this part of the American coast, is not far from Acapulco. It appears that the line of III. passes near San Blas, and also near the Bay of S. Magdalena on the coast of California. At Mazatlan, somewhat within the Gulf of California, the time is an hour or two later, as we should expect.

When we reach Monterey and S. Francisco, the hour is about VI. according to Capt. Beechey's observations. The more recent ones are too anomalous to proceed upon. At Port Bodega, in lat. 38°, we have the VIII. tide line; and at Nootka Sound, Cook's observations, which give $12^h\ 30^m$ (whence Greenwich IX^h. nearly), are confirmed by Capt. Kellet's observations in the Straits of Fuca, south of Vancouver's Island. The next point is the Russian settlement of New Archangel, in the island of Sitka, where the tides exhibit very curious features, as I have already stated, from the observations of Admiral Lütke*, and as I find further confirmed by the observations of Sir E. Belcher. The line belonging to Sitka appears to be IX. and a half.

From this point, we depend upon Russian observations which are given by Admiral Lütke in his "Notice." These enable us to see that the cotidal lines bend, as usual, deep into the head of the bay in which is Cook's river in lat. 60°. The coast here trends to the west, and the wave follows it and pursues its course along the chain of the Aleutian Isles, where it has been traced by Admiral Lütke and the navigators of the Russo-American Company. It appears that the lines of XI., XII., I., II., fall near this chain; and that the line of V. is near the coast of Kamtschatka. It is not difficult to arrange the cotidal lines so as to conform to these data.

Admiral Lütke has observed the tides at other places on the Asiatic coast, as far north as 65°, but I shall not attempt to arrange them.

* See Philosophical Transactions, 1840, Part I. p. 107.

33. Our next attempt must be to arrange the tides of the oceanic isles of the Pacific, taking in the first place those south of the Equator.

Isles of the Pacific (South).

	Lat. S.	Long. W.	Time, high water.	Greenwich time.		
	° ′	h m	h m	h m	feet.	
Easter Island	27 9	7 20	2 0	9 20	......	Norie.
Gambier's Group	23 0	9 0	1 50	10 50	......	Beechey.
Lagoon Island	18 0	9 18	12 30	9 48	......	Cook, Phil. Trans. 1772.
———	....	....	11 15	....	......	Lalande.
Marquesas.						
Resolution Bay	9 53	9 20	5 7	2 27	6	*Du Petit-Thouars.
Low Archipelago.						
Bow Island	18 6	9 23	6 30	3 53	1	*Belcher.
Tahiti	....	....	Anomalous.			*Belcher.
Tonga Isles.						
Annamooha	20 15	11 40	6 0	6 20		
Eooa	....	11 40	7 0	7 20		
Tongataboo	21 8	11 41	6 50	7 19		
Wallis Island	13 26	11 44	5 0	4 44	......	Zebra, R. B.
Feejee Islands.						
Nakulau	18 9	12 6	8 30	8 36	5	*Belcher. Diurn. ineq.
Mathuaha	....	....	5 30	....	6	*Wilkes (U.S.Ex.111.322).
Ooolau	....	....	6 10	....		
New Hebrides.						
Tanna, Port Resolution......	19 32	12 41	5 45	6 26	......	Lalande.
New Caledonia	20 17	13 2	6 30	7 02	......	Norie.
Norfolk Island	29 0	12 48	7 45	8 33	......	Norie.
New Zealand, Tobago Bay...	38 22	12 57	6 0	6 7	......	Cook.
New Ireland.						
Carteret's Harbour............	4 39	13 50	Anomalous.		......	*Belcher.

We have also the following observations given north of the equator.

Isles of the Pacific (North).

	Lat. N.	Long. W.	Time, high water.	Greenwich time.		
	° ′	h m	h m	h m	feet.	
Sandwich Isles.						
Honoloulou........................	21 18	10 32	3 35	2 7	2	*Du Petit-Thouars.
———	....	....	2 55	....	......	*Kotzebue.
Caroline Isles.						
Ualan	5 15	13 7	3 35	4 42	5	*Lütke.
Ladrone Isles.						
Guahan	13 32	14 20	8 23 ?	10 43	......	*Freycinet.
Bonin Isles......................	26 52	14 29	6 43	9 12	3	*Lütke.
———	....	....	6 3	....	......	*Beechey.
Loo Choo Isles	26 30	15 28	6 28	9 56	6	*Beechey.
Sand Isle, Samboango	6 55	15 52	7 36	11 28	4	*Belcher.
Bashee Group.						
Baton Isle	22 0	15 50	....	....	......	*Belcher.
Corean Archipelago	34 17	15 51	4 49	8 40	13	*Belcher. Anomalous.
Patchusan	26 20	15 41	6 36	10 17	5	*Belcher. Diurn. in.
Hong Kong	22 12	16 23	9 37	2 0	6	*Belcher. Diurn. in.
Amoy Harbour	24 16	16 8	12 52	5 0	18	*Capt. H. Smith.
Santubon	1 48	16 39	4 21	9 0	12	*Belcher.

These observations, especially those south of the equator, appear to imply a general motion westward of the tide-wave; but I conceive that they are much too few and too unconnected to justify me in drawing cotidal lines; besides which, the smallness of the tides in the central parts of the ocean makes the observations more than usually doubtful, and is accompanied by some circumstances inconsistent with the notion of a simple progressive wave as the representation of the tidal phenomena of those seas. I will consider those circumstances for a moment.

Tides of the Central Pacific.

34. The tides over a great portion of the central part of the Pacific are so small, that we may consider the lunar tide as almost vanishing. Thus at Bow Island it is stated as only one foot; at Tahiti it is hardly more; at the Sandwich Islands it is two feet; and even at New Ireland, where we are no longer in the central space, but among the larger islands to the west of it, the tide is only about two feet. But moreover at some at least of these places the tide, small as it is, is not the *lunar* tide following its ordinary laws. At Tahiti, for instance, the time of high water appears never to deviate from noon by more than a certain difference, although Sir E. BELCHER has shown that it varies from about nine o'clock in the forenoon to three in the afternoon*. At Bow Island there appears reason to believe that the limits are much the same, and perhaps at Carteret's harbour in New Ireland. Now it will easily be seen that such a result as this would follow, if we were to suppose the tidal influence of the sun and of the moon to be equal. On this supposition, it is plain that the high water would always occur half-way between the sun's transit and the moon's transit. Hence at new moon the high water would be at noon; as the moon went away to the eastward of the sun, the tide would be later and smaller; till, when the moon was at 6^h distance from the sun, the tide would be at 3^h; but would in fact vanish. After this point, the tide would reappear at 9^h A.M., or a little later, the inferior transit of the moon now taking the place of the superior one, in determining the tide; and from this time the tide would be gradually later and larger, till, at full moon, it would again be at noon; and so on. This appears to agree pretty well with the phenomena of the tides at Tahiti, as determined by Sir E. BELCHER.

35. A more minute examination of the tides in these regions will enable us to pronounce more decidedly whether the law of the phenomena is that which has been just stated. And if it appear that the phenomena do follow this law, we shall have further to consider how such a motion of the sea in those parts is to be combined with the very different movements which occur in other places, and what is the general movement of the ocean which they indicate; whether, for instance, they are best explained by looking upon the solar and lunar parts of the tide as produced by two separate waves, which may increase and diminish separately, and may start from different epochs in their motions. I shall not now pursue this point further; nor

* Philosophical Transactions, 1843, Part I.

shall I further examine how far the phenomena approach to the cases of fluid motion already described, in which there is a marked wave at the outskirts of the mass, and an approximate quiescence of the surface in the central parts; namely, the case of a stationary undulation, and of a revolving undulation*. I may remark, however, that the latter supposition, that of a revolving undulation by which the tide is carried from California northwards along the American shore and to the coast of Kamtschatka, while the cotidal lines converge to some central point in the North Pacific, would explain the smallness of the tides at the Sandwich Isles.

36. When we proceed westward from the central parts of the South Pacific to New Zealand and Australia, we again find the feature which we have already noticed in the tides; namely, that the cotidal lines run nearly parallel to the shore in its neighbourhood, but that we cannot easily infer the oceanic from the littoral tides; for the tide lines of VI., VII., VIII., IX., X., XI. succeed each other along the coast of New Zealand, and apparently double round its northern and southern extremities, as we should expect from the laws of fluids. But yet the line of X. recurs again on the coast of Australia, and is succeeded by later hours as we proceed northward and southward from about lat. 30° south. Cotidal lines may be drawn to accommodate themselves to these data; but of these lines the parts which occupy the ocean between New Zealand and Australia must be very doubtful.

I have been favoured by Sir James Ross with about a month's observations of the tides in the Bay of Islands in New Zealand, which I may refer to hereafter; but my means of tracing the *progress* of the tides along the coast of New Zealand still depend upon Captain Cook's statements†. The longitude of New Zealand is so nearly 12^h that the local tide-hour may be considered as coincident with the Greenwich hour. At Tobago Bay, near the most easterly point of these islands, the time is 6^h. In proceeding to Mercury Bay and the Bay of Islands on the north-east coast, it becomes $7^h\ 30^m$ and 8^h respectively. And in proceeding southward from Tobago Bay, we have also a retardation. At Queen Charlotte's Sound and Admiralty Sound, in Cook's Strait, which separates the two islands, it is $9^h\ 30^m$ and 10^h, the strait producing a considerable retardation. At Dusky Bay, the southern point of the island, the time is $10^h\ 57^m$.

Tides of Australia.

37. With regard to the coast of Australia, I have been furnished with a considerable quantity of tide observations, resulting principally from the surveys of Captain Blackwood and Captain Stokes. These are now to be added to the observations formerly collected from Captains Cook, Flinders and King. The earliest tides, as I formerly observed, appear to occur between the latitudes 24° and 35° south. I shall therefore proceed from this part southwards and northwards.

* Or rather a revolving cotidal line. See Article 23.

† Philosophical Transactions, 1772.

In the case of the recent observations I have given, not the "establishment," but the original observations, from which, of course, the establishment is to be deduced. It is much more satisfactory to have the observations themselves than a conventional mode of expressing the result; but the attempt to combine the two classes of data shows the difficulty into which we are led by this convention of an "establishment" in the vulgar sense. For instance, at Port Bowen, the time of high water at new moon is $9^h\ 46^m$; but the interval at which the tide follows the moon varies from $8^h\ 37^m$ to $11^h\ 9^m$. The mean of these, the *corrected establishment*, is $9^h\ 53^m$; and in general the vulgar establishment is, as I have said, about 30^m greater than this, and therefore would here be $10^h\ 23^m$. The great discrepancy of the "establishment" obtained in these two different ways, arises from an anomalous course of the lunitidal intervals which appears in these observations, the mean interval being considerably removed away from the days of new and full moon. But the same discrepancy appears more or less in most cases. I combine the old and new observations as fairly as I can.

Australia (North side).

	Lat. S.	Long. E.	Time, high water.	Greenwich time.		
	° ′	h m	h m	h m	feet.	
Botany Bay	34 0	10 4	8 0	9 56	....	Cook, Flinders.
Hervey's Bay	24 40	....	8 0	....	....	Flinders.
Bustard Bay	24 30	....	8 0	....	....	Cook.
Port Curtis	23 52	....	8^h to 9^h	....	....	Flinders.
Keppel Bay	23 8	....	9 30	....	....	Flinders.
Port Bowen	22 28	10 3	10 0	11 57	15	Flinders.
Strong-tide Passage	....	....	10 0	....	....	*Blackwood.
Shoalwater Bay	....	....	10 30	....	....	Flinders.
Thirsty Sound	22 6	....	10 45	....	....	Flinders.
Broad Sound	....	....	11 0	....	....	Flinders.
Percy Islands	21 19	....	11 0	....	....	Flinders.
Cumberland Isles	....	....	11 0	....	....	King.
Cape Upstart	19 40	9 51	10 30	12 39	....	*Blackwood.
Endeavour River	15 27	....	9 30	....	....	Cook.
Princess Charlotte's Bay	14 20	....	8 0	....	....	King (ii. 251).
Endeavour Strait	10 37	....	1 30	....	....	King (ii. 251).
Murray's Island, Torres Straits	9 55	....	10 30	....	....	Flinders.
Endeavour Straits	....	9 25	1 30	4 5	....	Cook.
Liverpool River and Goulburn Island	....	....	6 0	....	....	King (ii. 309).
Port Essington	11 22	8 48	4 48	8 0	....	*Sir Gordon Bremer.
Saint Asaph's Bay	....	....	5 45	....	....	King (ii. 237).
King's Cove	....	....	5 15	....	....	King (ii. 237).
Vansittart Bay	....	8 22	9 15	12 53	....	King (ii. 324).
Montague Bay	....	....	12 0	....	....	King (ii. 324).
Canning Bay	....	8 20	12 0	3 40	....	King (ii. 324).
Prince Regent's River	....	....	12 0	....	....	King (ii. 324).
Roebuck Bay	....	8 8	....	....	30	King, Dampier.

The tides at Port Essington will be the subject of more special consideration hereafter. But I shall first consider the progress of the tide to the south side of Australia.

Australia (South side).

	Lat. S.	Long. E.	High water. Greatest interval.	High water. Least interval.	Mean.	Low water. Greatest interval.	Low water. Least interval.	Mean.	Greatest range.	Least range.	Diurnal inequality.
	°	h m	h m	h m		h m	h m		ft.	ft.	
Cape Upstart	20	9 50	11 0	9 0	10 0	6 30	2 40	4 35	10	2	Not observed. *Belcher.
Port Bowen	22½	10 3	10 40	9 0	9 50	4 30	2 30	3 30	15	1	High water, 3 ft.; low water, 1 ft. *B.
Bass's Straits.											
Kent's Group	39½	9 49	11 50	9 40	10 45	5 40	4 0	4 50	6½	6	Low water? *Stokes.
Port Refuge	39	9 45	11 36	10 50	11 13	5 14	4 28	4 51	6	5½	High water? low water, 2 ft. *Stokes.
Western Port	38½	9 41	1 30	1 0	1 15	7 40	7 0	7 20	6	5	High water, 2 ft.; low water, 2½ ft. *S.
Port Phillip	38	9 38	12 48	11 0	11 54	7 10	4 50	6 0	3	2	Low water? *Stokes.
Preservation Island ...	40½	9 52	11 12	10 40	10 56	5 30	4 50	5 10	7	4	Low water, 2 ft. *Stokes.
Swan Island	41	9 52	10 20	9 40	10 0	4 50	3 12	4 1	6	3	
Port Dalrymple	41	9 47	12 14	11 24	11 49	7 36	5 40	6 38	9	6	High water? low water, 3 ft. *Stokes.
Circular Head...........	41	9 41	12 0	11 38	11 49	6 0	5 14	5 37	9	7	High water? low water, 2½ ft. *S.
Three Hummock Island	40½	9 36	12 20	11 30	11 55	6 30	4 50	5 40	6	5	High water, 1 ft.; low water, 1 ft. *S.
Adelaide	35	9 14	6 24	3 24	4 54	13 0	9 30	11 15	7	3	High water, 3 ft.; low water, 1 ft.
King George's Sound...	35	7 52									
Swan River...............	32	7 43	10 48	7 0	8 54	8 48	6 30	4 39	3	1	Single day tides. Flinders. King.
Latitude Island	28¾	7 35	11 0	9 12	10 6	5 30	3 0	4 15	2	1	Di. in. of *times*, high and low water. *S.
East Wallaby	28¾	7 35	11 30	8 0	9 45	6 10	2 30	4 20	2	1	Di. in. of t. and h. H.W. and L.W. *S.
Depuck Island	20½	7 50	12 0	10 12	11 6	5 30	4 12	4 51	14	6	High water, 2 ft.; low water, 2 ft. *S.
Port Essington	11	8 48	3 30	2 0	2 50	10 12	9 0	9 36	8	2	High water, 2 ft.; low water, 8 ft.

Supposing the "establishment" of a place on this coast to be about 30^{m} more than the mean lunitidal interval (that is, than the *corrected establishment*), we can connect them with the preceding observations. Thus we shall have

	Long. West.	Time of high water.	Greenwich time.
Port Phillip	$14^{h}\ 22^{m}$	$12^{h}\ 24^{m}$	$2^{h}\ 46^{m}$
Adelaide	14 46	5 24	8 10
Port Essington	15 12	3 20	6 32
Swan River	16 17	9 24	1 41

At Adelaide I have a considerable series of observations which deserve special attention.

38. I have now put together all the principal materials which I have procured for determining the course of the tides of the Pacific. But it is apparent from what has been said, that the materials are insufficient to give us any complete or consistent view of the tidal movements of the waters of that ocean and the neighbouring seas.

39. I may observe, moreover, that there appears to be little chance that our knowledge of these tides will ever be much increased by observations made in voyages principally directed to other objects. Although, in the surveying and exploring voyages since Captain King's, many tide observations on the coasts and at the islands of the Pacific have been made, and many of them with care and skill, we have scarcely any material fact added to our knowledge; and the cotidal lines for the shores of America, New Zealand and Australia, as I drew them in 1833, remain with scarcely any alteration. Cook's observations at New Zealand, for instance, are for this purpose, better than any since made, because they are connected (being made by the same navigator and in close succession) and extend along a continuous shore. It is only by observations thus connected and having some degree of geographical continuity, that we can hope to trace the course of the tides.

I add a very slight and imperfect sketch of the cotidal lines of the Pacific as they result from the materials just examined. (See the Plate.)

The Diurnal Inequality.

40. There is a feature in the tides, very important both in its practical effect and in its bearing upon the theory, which has long been, in some degree, known to navigators, but of which they do not seem sufficiently to appreciate the generality, and of which they have commonly mistaken the law. I speak of the difference of the two tides on the same day, which I have termed the *Diurnal Inequality*. It was noticed at Plymouth and at Bristol as long ago as the time of NEWTON, and was, to a certain extent, explained by him. It was shown by LAPLACE to exist in the tides at Brest. It was found by Captains COOK, FLINDERS and KING, to be very large on the coasts of Australia. Its amount at Sincapore is enormous. Admiral LÜTKE found it to obtain in all his observations in the North Pacific. It appears in most parts of the Atlantic; and it is very considerable at the Falkland Isles, at Cape Horn, at New Zealand and at Kerguelen's Island. Indeed the cases where it does not occur are the exceptions, and commonly belong to shores where two tides are combined, as in the east coast of England, where it is nearly obliterated.

41. I have said that the laws of this inequality have commonly been mistaken. Thus navigators have spoken of the difference of *day* tides and *night* tides. Captains COOK, FLINDERS and KING, say that on the coast of Australia the night tides are *always* greater than the day tides. I have shown* that the seeming truth of this assertion was occasioned by the time of year at which those navigators respectively made their observations. Lieut. WILKES† says that on the coast of the Nisqually Indians in the Oregon Territory, the day tides during his observations were two feet higher than the night tides. This also was only a temporary rule. No reference of the inequality to day tides and night tides, or morning tides and evening tides, can express its law. It depends upon the moon's declination, and changes to alternate tides when the moon's declination changes from north to south, and *vice versâ*. Its rule is expressed in the following form‡:—

For moon's N. declination. { *Add* to the tide following moon's South transit,
Subtract from the tide following moon's N. transit,

For moon's S. declination. { *Subtract* from the tide following moon's S. transit,
Add to the tide following moon's N. transit,

the quantity added or subtracted being greater as the declination is greater; and the declination being taken for one, two, or three days previous to the tide. According to this law, the inequality has been introduced into the Tide Tables for Liverpool, Bristol and Plymouth.

It may be worth while to show that the rule of the diurnal tide which has just

* Philosophical Transactions, 1833, p. 221.
† United States Exploring Expedition, iv. 417.
‡ Philosophical Transactions, 1837, p. 84.

been given may, *for some months*, produce the effect of making the afternoon tides greater than the morning tides, or *vice versâ*. Suppose the place to be one where the tide happens (in general terms*) soon after the moon's (*south* or *superior*) transit; then, beginning from new moon, the afternoon tide for a fortnight follows the south transit of the moon. Supposing that during this fortnight the moon has north declination; then the diurnal inequality is additive by the rule, and therefore the afternoon tide is, during this fortnight, the highest. Now at the end of a fortnight of north declination, the declination changes to south. But at the end of a fortnight, the afternoon tide begins to be that which follows the *north* or *inferior* transit of the moon; and therefore again, by the second part of the rule, the inequality is still additive, and the afternoon tide is still the greater. And this will continue to be the case till the points of no lunar declination are shifted away from the syzygies by the motion of the moon's nodes relative to the sun. But if the declination pass from north to south, or the reverse, at a different period from that which transfers the afternoon tides from one transit to the opposite one, we shall no longer have this apparent constancy in the relation of morning and afternoon tides. If, for instance, the tide-hour being such as has already been supposed, the change of declination, north and south, takes place when the tide is at four, five, six or seven o'clock; the afternoon tide will then (or rather one or two days later) change from being the greater to being the less, or *vice versâ*. Or if the tide-hour be six o'clock, the tide being (in general terms) six hours after the moon's transit, the afternoon tide will follow a south transit of the moon from the time when the moon is six hours west of the sun to the time when she is six hours east of him, and then change and follow a north transit; and so on alternately. Hence, if in this case the moon's ascending node be at six hours west from the sun, the declination will be north while the afternoon tide follows a south transit, and therefore the afternoon tide will be the greater for the whole lunation. But if, in this case, the node be in conjunction with the sun, the afternoon tide will change from smaller to larger, or the reverse, at the syzygy, that is, when the tide is at six o'clock; or rather, as I have said, a day or two later.

42. This last-mentioned circumstance, that the change in the features of the tides takes place a day or two, or perhaps longer, after the astronomical configuration by which it is determined, is common to all the empirical laws of the tides, as I have repeatedly remarked in the memoirs on this subject already published in the Transactions. It has recently been shown by Mr. AIRY† that this is a result which follows from supposing the tidal motions of the sea to be affected by friction. The amount of this retardation of the phenomena for each place, or, as we may term it, the "age of the tide" relative to this particular phenomenon, the diurnal inequality, is different for different places; and must, for each place, be learnt from observation.

43. The account which I am now giving of the diurnal inequality supposes it to depend upon the moon alone; and so, for most purposes, it does almost entirely, as

* I leave out of consideration, in this explanation, the semimensual inequality.

† Tides and Waves, 452.

to its law, and in a very great degree as to its amount. The sun also will of course produce a diurnal inequality, which will depend upon his motions by laws similar to those which have been mentioned, and which will combine with and modify the lunar diurnal inequality. The determination of the solar, as well as of the lunar effect, is requisite, both for the construction of accurate Tide Tables for each place, and for the comparison of the tides with their theory. But this regard to the solar effect is not needed, either to make up such a general view of the progress of the tides as that at which I here aim, or to predict the general course of the tides so as to know whether the morning or afternoon tide will be the greater.

44. In stating that the lunar diurnal inequality alone appears in a conspicuous form in the facts, I do not rest merely upon theoretical views or upon a few cases; but am able to show it to be so, by numerous, distant, and extensive series of observations. These observations also enable me to trace the course and modifications of the diurnal inequality along the greater part of the shores of the Pacific; and I shall state their general results for that purpose.

I shall make this statement in words and figures, without offering to the reader any of the diagrams by which the results have been obtained. I am still of opinion that by far the best method of discussing tide observations is to lay down the original observations (both the heights and the lunitidal intervals) as the ordinates of curves. When this is done, the eye perceives at once several of the leading features of the case; the diurnal inequality and the semimensual inequality, especially. It perceives also where the glaring anomalies are; and we can often thus discern what amount of correction of the observations, on the ground of their general tendency, is allowable; and whether, as sometimes happens, the anomalies are so great that the observations are worthless.

45. The mode in which the diurnal inequality shows itself when tide observations are thus laid down in curves, has already been presented repeatedly in the Transactions; especially in the Sixth and Seventh Series of these Researches*. The inequality of heights appears in the *zigzag* form of the line drawn through the summits of the ordinates which represent the heights of successive tides. This zigzag structure is sometimes of a moderate degree of abruptness, as in the tides of the coast of North America, and of Portugal † and those of Plymouth ‡, and sometimes extremely abrupt, as the heights of low water at Sincapore §. In this latter case, the diurnal inequality sometimes makes a difference of no less than *six feet* between the height of the morning and afternoon tide; the whole rise of the mean tide being only seven feet at springs, and the difference of mean spring and neap tides not more than two feet.

In the new observations which I have before me, there are other cases, quite as extraordinary as that of Sincapore. I shall now begin to state the general aspect of the diurnal inequality, as given by my new materials.

* Philosophical Transactions, 1836, Part II.; 1837, Part I.

† Ibid. 1836, Plate XXVII.

‡ Ibid. 1837, Plate II.

§ Ibid. Plate III.

The Diurnal Inequality from Observations.

46. I shall follow the same order of place which I have employed in stating the tide-hours. The amount of the diurnal inequality given is the greatest difference of the two successive tides.

FALKLAND ISLES. *Port Louis.*—An excellent series of observations by Sir JAMES C. ROSS, beginning May 10, 1842. Nine semilunations complete; and the dependence of the diurnal inequality on the moon's declination throughout regular.

High water heights: diurnal inequality = 2 ft. Difference of mean springs and neaps = 2 ft.

Low water heights: diurnal inequality = 2 ft. Difference of mean springs and neaps = 2 ft.

The age of the diurnal inequality is about a day and a half.

CAPE HORN. *St. Martin's Cove.*—Observations by Sir J. ROSS. Three semilunations, tolerably regular. Sir J. ROSS himself remarks*, that the diurnal inequality† "is as great here as at the Falkland Isles, and at first seemed to present most unaccountable irregularities; but the limited period of observation did not admit of thorough investigation."

High water heights: diurnal inequality = 2 ft. Difference of mean springs and neaps = $1\frac{1}{2}$ ft.

Low water heights: diurnal inequality = $1\frac{1}{2}$ ft. Difference of mean springs and neaps = $1\frac{1}{2}$ ft.

High water times. There is a large diurnal inequality in the lunitidal intervals, amounting sometimes to $2\frac{1}{2}$ hours, while the semimensual inequality also appears to amount to two hours.

The following results are derived from the new observations already quoted:—

CALLAO.—No definite result. See before.

GUAYAQUIL. *Puna Is.*—Apparently diurnal inequality in high water heights.

PANAMA.—No apparent diurnal inequality.

NICOYA.—High water heights: diurnal inequality = 1 ft. Low water heights: diurnal inequality = $\frac{1}{2}$ ft.

REALEJO.—High water heights: diurnal inequality = 1 ft. Low water heights: diurnal inequality = $\frac{1}{2}$ ft. Apparently diurnal inequality in the high water and low water times, but irregular in the observations.

ACAPULCO.—Apparently diurnal inequality, but small and doubtful.

MAGDALENA BAY.—High water heights: diurnal inequality = 1 ft; low water heights, not apparent. High water times: diurnal inequality = $2\frac{1}{2}$ hours: but these results doubtful, from the shortness of the series and its irregularity.

COLUMBIA RIVER.—Diurnal inequality not apparent.

KING GEORGE'S SOUND.—High water heights: diurnal inequality = $1\frac{3}{4}$ ft.

* Voyage, ii. 313.

† He says "the semidiurnal inequality," but it is plain that he means our diurnal inequality.

San Francisco.—High water heights: diurnal inequality=2 ft. Low water heights: diurnal inequality $= 3\frac{1}{2}$ ft. High water times: diurnal inequality = 2 hours. Low water times: diurnal inequality = 2 hours?

Sitka.—High water heights: diurnal inequality $= 2\frac{1}{2}$ ft. Low water heights: diurnal inequality = 4 ft. High water times: diurnal inequality = 2 hours. Low water times: diurnal inequality $= \frac{1}{2}$ hour: irregular. North of this point the observations are too imperfect to show diurnal inequality till we come to

Kamtschatka. *Petropaulofsk.*—High water heights: diurnal inequality = 1 ft. Low water heights: diurnal inequality = 4 ft. High water times: diurnal inequality = 4 hours. Low water times: diurnal inequality = 1 hour.

The tides of Sitka and Petropaulofsk have already been noticed in the Philosophical Transactions*. I there pointed out the large diurnal inequality of times at high water, and of heights at low water, which these places exhibit;—also the curious fact, that apparently the maximum and zero of the diurnal inequality of high water do not coincide in time with those of low water, but rather alternate with them.

47. I proceed to the islands of the Pacific.

Bow Island.—There appears to be a diurnal inequality of the time of high water, but necessarily doubtful, from the smallness of the tide.

Tahiti.—Here also there appears, in a portion of the tides, to be an alternation of late and early, approaching to the nature of diurnal inequality.

Feejee Islands.—High water heights: an evident diurnal inequality of half a foot.

New Ireland.—Something of the nature of diurnal inequality in the high water times, but very doubtful.

Corean Archipelago. Black Island.—High water heights: diurnal inequality = 2 ft. High water times: diurnal inequality = 2 hours.

New Zealand. Bay of Islands.—A series of observations including two semilunations by Sir J. C. Ross.

High water heights: diurnal inequality $= \frac{1}{2}$ ft.: very regular.

High water times: diurnal inequality $= 1\frac{1}{2}$ hour: regular.

We now come to Australia, and have the following results for the *heights*:—

	Diurnal inequality.	
Cape Upstart	Not observed.	
Port Bowen	High water, 3 ft.	Low water, 1 ft.
Bass Straits.		
Kent's Group		Low water?
Port Refuge	High water?	Low water, 2 ft.
Western Port	High water, 2 ft.	Low water, $2\frac{1}{2}$ ft.
Port Phillip		Low water?
Preservation Island . .		Low water, 2 ft.

* 1840, Part I. p. 161.

		Diurnal inequality.	
Port Dalrymple	. . .	High water?	Low water, 3 ft.
Circular Head	. . .	High water?	Low water, $2\frac{1}{2}$ ft.
Hummock Head	. .	High water, 1 ft.	Low water, 1 ft.
Adelaide	. . . . .	High water, 3 ft.	Low water, 1 ft.

48. For PORT ADELAIDE I have been furnished with twelve months' observations made by Mr. BEALTON, Tide Surveyor at that Port.

Of these I have thrown the high water heights of ten semilunations into curves, and the result is very striking to the eye. There is a diurnal inequality which, for the months of December and January 1839, amounts to no less than four feet. In the succeeding months it is smaller, but equally regular as to its law. It follows the moon's declination with great regularity, at an interval of two days, altering from tide to alternate tide as the declination alters from north to south, and reversely. Its amount when greatest is nearly an inch for each degree of lunar declination. Probably a further discussion of these observations would show why the diurnal inequality for January, February, March 1840, is less than that for the two preceding months: but my present purpose does not require this labour. We may hope that these tides will receive a full discussion from some local mathematician.

49. At King George's Sound, near the south-west point of Australia, there is a large diurnal inequality of the times, which sometimes reduces the two daily tides to one*. Proceeding onwards to the western coast of Australia, and the settlement of Swan River, we find the diurnal inequality assuming new forms. The islands called Houtman's Abrolhos, in latitude 29° S., have been surveyed by Captain STOKES, and tide observations made at East Wallaby Island; of which the following is the result:—

EAST WALLABY ISLAND.—High water heights: diurnal inequality $= 1\frac{1}{2}$ ft. Low water heights: diurnal inequality $= \frac{1}{2}$ ft. High water times: diurnal inequality $= 5$ hours. Low water times: diurnal inequality $= 2$ hours.

As the rise of the surface at this point is only about two feet altogether, there may be some doubt of the times; but the observations are remarkably regular and consistent.

The observations made at Rat Island, another of the same group, agree in the general character of the results.

If we proceed to the north along this coast, and pass round the N.W. Cape of Australia to Depuck Island, in latitude $20°\frac{1}{2}$ S., longitude $7^h\ 51'$ E., we have (still from Captain STOKES's observations) a marked diurnal inequality of the heights, both high and low water, amounting to two feet in a tide of $14\frac{1}{2}$ ft.; but we discern no regular diurnal inequality of the times.

As apparently more connected with the South of Australia than with any other continental coast, I may here notice Kerguelen's Island in latitude 49° S. longitude $4\frac{3}{4}^h$ E. It appears by the observations of Sir J. Ross in 1840, that here also there is a large

* Philosophical Transactions, 1837, Part I. p. 83.

diurnal inequality, apparently amounting to one or two hours, in the time of high water, but no conspicuous diurnal inequality in the heights. The inequality or irregularity of the times is so great, that it is difficult, at this place, to speak of a tide-hour. The lunitidal interval varies from $11\frac{1}{2}$ hours to $16\frac{1}{2}$ hours.

50. I shall not entangle myself in the seas broken by innumerable large and small islands which extend from Torres Straits to the coasts of India, Arabia, and Africa; but I may observe that in these Indian seas the diurnal inequality is very marked in general, as I have already noticed for several places. I will refer back to these.

Phil. Trans. 1839, Part I. p. 164. Bassadore, at the entrance of the Persian Gulf.—A very large inequality of the times, amounting in some instances to more than *two hours*.

Surat and Gogah, in the Gulf of Cambay.—A large diurnal inequality in the heights of high water, amounting to not less than seven or eight feet. The age is two days.

Phil. Trans. 1833, p. 221. The River Hoogly.—The night tides highest from November to February: the day tides highest from March to October.

Phil. Trans. 1833, p. 224. Tonquin.—One tide in twenty-four hours.

Phil. Trans. 1837, Part I. p. 78. Sincapore.—A very large diurnal inequality, high water heights, diurnal inequality $= 1\frac{1}{2}$ ft. Low water heights, diurnal inequality $= 6$ ft.

The age of the diurnal inequality is a day and a quarter.

This very large diurnal inequality in the low water heights of Sincapore was, so far as I know, a new fact, when it was thus extracted from the observations, and was probably looked upon by most persons as a singular case. There is however good reason to believe that the same fact extends over the whole of the sea in that region. At least I have the means of showing that it prevails on the north coast of Australia, namely, at Port Essington.

51. PORT ESSINGTON.—I am supplied with a considerable series of observations, somewhat interrupted, made by Sir GORDON BREMER, of which I have thrown five semilunations into curves. The observations indicate a diurnal inequality in the high water heights, but not very regularly. But at low water there is a diurnal inequality, of which the magnitude is not less than four feet, and this appears to be regular. The observations however are not exact enough to determine the age of this diurnal inequality.

I will add, as apparently connected with this, a reference to the peculiarities of the tides in the Gulf of Carpentaria. FLINDERS found only one ebb and one flood in the day, as I have noticed*.

I may remark, that the phenomena involved in the diurnal inequality are very curiously distributed to some of our principal colonies in Australia. At Adelaide, on the south, there is a large diurnal inequality in the *heights* of *high* water: at Port Essington, on the north, this inequality falls mainly upon the *low* water; while at

* Philosophical Transactions, 1833, p. 225.

Swan River, on the west, it principally affects the *times*. And the diurnal inequality which alters the low water four feet at Port Essington, and six feet at Sincapore, affects the high water to a still greater extent in the Gulf of Cambay, and disturbs the times at the entrance of the Persian Gulf.

Where the diurnal inequality affects the heights so much, it probably affects materially the time of tide in all places, as we know it does in some. And therefore over the whole of the Indian seas, the terms "establishment" and "tide-hour" must, without further explanation, be very ambiguous. And as we cannot know what facts are designated by such terms in books of navigation, all attempts to found upon such statements a coherent view of the tides of those seas, must be very precarious*.

52. Upon the occasion of the great series of tide observations made in 1835, I was led to trace the progress of the diurnal inequality wave along the coast of Europe. This I attempted in the Eighth Series of these Tide Researches†. The difficulty of separating the diurnal from the semidiurnal wave was there in some degree overcome. But even in that case, the problem was very imperfectly solved; for the coasts of the Pacific, and even for the coasts of Australia, our materials are too scanty and disconnected to give us any hope of success at present, if we were to attempt the same problem. With due materials, the diurnal inequality appears plainly to be separable from the semidiurnal tide; for it sometimes affects high water most, sometimes low water; sometimes the heights, sometimes the times; and is large sometimes when the semidiurnal tide is small, and sometimes exceeds the semimensual inequality.

53. It was remarked also, on the occasion of the observations of 1835‡, that the diurnal inequality on the coast of North America followed the changes of the moon's declination almost instantaneously; while on the coasts of Portugal, Spain and France, the changes of lunar declination were represented in the diurnal inequality two or three days later; and at the Cape of Good Hope, about the same time. I have already noticed that this feature throws great difficulty in the conception of that motion of the waves by which the tides are produced. It suggests the necessity of some new mode of conceiving that motion; a subject which I shall not here pursue.

* Philosophical Transactions, 1833, p. 200. † Ibid. 1837, Part II. ‡ Ibid. 1836, Part II. p. 302.

Trinity Lodge, Cambridge,
Nov. 8, 1847.